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RECENT DETERMINATIONS OF STELLAR PARALLAXES BY PHOTOGRAPHIC METHODS. A REVIEW

BY ROBERT G. AITKEN

1. "Parallaxes of 260 Stars, Derived from Photographs," by S. A. Mitchell, assisted by C. P. Olivier, H. L. Alden and others. *Publ. Leander McCormick Obsy.*, Vol. III, 1921.

2. "Photographic Determinations of Parallaxes at the Allegheny Observatory," by Frank Schlesinger. *A. J.*, **33**, 9, 1920. (The details of these 269 parallaxes and of 50 earlier ones are given in *Publ. Allegheny Obsy.*, Vols. 4 and 5, 1920, which (except Vol. 4, No. 1) have been distributed quite recently. The several papers in these volumes are signed by Dr. Schlesinger and ten assistants.)

3. "Parallaxes of Fifty-two Stars," by Georges Van Biesbroeck and Mrs. Hannah Steele Pettit. *Publ. Yerkes Obsy.*, Vol. IV., Pt. III, 1920. (Vol. IV, Pt. I, 1917, gives details of 103 parallaxes determined earlier by Slocum, Mitchell, Lee, Joy, and Van Biesbroeck, with a summary of the 28 determined by Schlesinger at the same observatory.)

4. "The Parallaxes of Fifty Stars Determined at the Sproul Observatory. Second List," by John A. Miller, with the cooperation of John H. Pitman and Hannah B. Steele. *Sproul Obsy. Publ.*, No. 5, 1920. (No. 4 of these PUBLICATIONS, issued earlier, contains the first list of 50 parallaxes.)

5. "The Photographic Determination of Stellar Parallaxes with the 60-inch Reflector, Fourth Series," by Adriaan van Maanen. *Contrib. Mt. Wilson Obsy.* No. 182, 1920. (*Contrib.* Nos. 111, 136, and 158 contain van Maanen's earlier parallax series derived since 1915 with the same telescope. In all 110 parallaxes are listed, including those of several nebulae.)

The mere reading of the titles given above will impress one with the progress that is being made in our knowledge of stellar parallaxes. The total number of parallaxes separately listed in these papers is 972; a small number in comparison with the many millions of stars visible in our great telescopes, but a large one indeed in comparison with the total number of parallaxes available a decade or two ago. Sir Frank Dyson is authority for the statement that in 1880 we had values for the parallax of about 20 stars; in 1900, for about 60; in 1915, for perhaps 200. While I have not made a detailed comparison of the various lists, to eliminate the duplicates, I think it safe to say that we now have published parallax values for about 900 stars. It is anticipated that this number will increase at the rate of perhaps 200 a year, for the institutions issuing the papers enumerated, together with the Dearborn Observatory and the Royal Observatory[1] at Greenwich, England, are carrying on the work vigorously on a plan of cooperation formulated by the Stellar Parallax Committee appointed by the American Astronomical Society about five years ago.

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[1] The paper entitled "Stellar Parallaxes Determined at the Royal Observatory, Greenwich," communicated by the Astronomer Royal to the *Monthly Notices R. A. S.* (**75**, 592, 1915) contains 40 parallaxes derived by essentially the same methods as those employed in the more recent work. A second list of Greenwich results is published in *Monthly Notices R. A. S.* **81**, 32, 1921, received after this article was in type.

The quality of the work, the remarkable accuracy attained, is even more notable than its quantity. Reading the several papers before us, we find that all of the observers have given the most scrupulous attention to every detail of the work in the effort to free the final results from systematic error and to reduce the unavoidable accidental errors of measure to the minimum. The observations are all photographic and in taking the plates the observers have all heeded the "reasonable precautions" first insisted upon by Kapteyn in 1900. These are, to keep the telescope always on the same side of the pier, to photograph the stars only when they are very close to the meridian and to "guide" with all possible care. Two of these precepts are easily followed; but with even the most skilful guiding the star images cannot be kept quite stationary on the plate during an exposure, and the minute excursions they make affect the positions of the bright star images more seriously than those of faint stars. All recent observers have therefore adopted the device introduced by Schlesinger in his epoch-making work at the Yerkes Observatory in the years 1903 to 1905. That is, they have reduced the image of the parallax star on the plate to the same brightness as that of the selected comparison stars by placing a small, rapidly rotating disk just in front of the photographic plate. A small open sector in this disk, adjustable to any desired angular aperture, permits the light from the parallax star to reach the plate for only a small fraction of the time required for each revolution of the disk.

It follows that the first condition the comparison stars must fulfil is to be of equal brightness. Three is the minimum number of stars required, but all observers prefer a larger number. Most of them are content with four or five and see little advantage in the use of a larger number; van Maanen, however, and the Greenwich observers, use at least eight whenever possible. The second condition is that the mean of the positions of the comparison stars on the plate should agree closely with the position of the parallax star. Having selected the comparison stars, the sector in the rotating disk is adjusted—by repeated trials, if need be—until the image of the parallax star just equals their images.

Stars as faint as the tenth or eleventh magnitude are almost invariably chosen as comparison stars. It may not be amiss to say that this choice is dictated by the two conditions just named, and not by the fact that such stars are more likely than brighter ones to have no appreciable parallax or proper motion. In general, it is impossible to find near the parallax star three or more brighter stars which fulfil the required conditions. The fainter stars are far more numerous and it only rarely happens that at least three suitable ones are not available. So far as the parallax at least is concerned, the brighter stars would doubtless be just as satisfactory, for it may be questioned whether more than one star in two thousand is near enough to have a measurable parallax and the probability is therefore small indeed that more than one such star will fall within the limits of any given plate except in the case of binary or other physical stellar systems. If another star, in addition to the one whose parallax is being measured, does show appreciable parallax (or proper motion), it may quite well be one of the fainter stars. In fact, in a very few instances in the work now under review such faint parallax (or proper motion) stars have been detected and rejected as comparison stars.

In minor details there is some variety of practice. Some observers impress only two images of each star upon every plate, others three or four; some take four or five (rarely more) plates at each of three successive opposite seasons of the year (the minimum length of time required), others three plates at each five or more seasons. The latter practice is commending itself ever more strongly, chiefly because it permits a more accurate determination of the proper motion and therefore a more complete elimination of its effect upon the computed parallax. For reasons of economy in money and in time some observers imprint two different star fields on each photographic plate, a plan that is quite feasible tho it entails some obvious inconveniences. Most observers develop each plate immediately, but some store the plates and photograph upon them the same fields at a second season before developing. These variations in practice have little or no effect, apparently, upon the probable errors of the results.

To insure plate measurements which shall be accurate and free from systematic error, the scales and screws of the measuring engines have been carefully investigated and the precaution has always been taken to measure each plate twice, its position being changed by 180° between the two sets of measures. Most of the observers have then employed the ingenious "method of dependences" in making their calculations (or "reductions"); van Maanen, however, uses a stereo-comparator instead of the usual measuring engine, and employs a different method of reduction.

The two questions of greatest interest about these or any other parallaxes are (1) how accurate are they? and (2), do they always give us the real distance of the star observed? The size of the probable errors affords a measure of the precision with which the work has been done. In all of the measures before us these errors are very small, not often exceeding ±0″.01. Thus Mitchell finds that the "*p. e.*" of the 260 McCormick parallaxes[2] is ±0″.0091; Schlesinger, for the 319 Allegheny results, finds ±0″.0081 and Boss, in his paper on the "Systematic Corrections to Stellar Parallaxes,"[3] assigns ±0″.0059 to the Mount Wilson results.

The systematic errors, however, are more important than the accidental errors of measure, as a very simple illustration will show. If one uses a footrule which is very slightly too long or too short, all distances measured with it are systematically too long or too short whatever care may be exercised in making the actual measures. The systematic errors have unquestionably been investigated by all of the observers but Mitchell and van Maanen are the only ones who give any details of their investigations in the present publications. After making a number of independent tests, Mitchell concludes that "the systematic error of the McCormick parallaxes is less than 0″.001; van Maanen's conclusion is that "the systematic error of the Mount Wilson trigonometrical parallaxes does not appear to exceed 0″.001 or 0″.002; it seems to be independent of both right ascension and proper motion."

Dr. Benjamin Boss, in the paper cited above, has made an elaborate investigation of the systematic errors of all available reliable series of parallaxes, including those here under discussion. He finds evidence in all of them of a systematic error depending upon the star's right ascension, but in the photographic series (and some others) this is very small. Disregarding the terms due to the right ascensions, he concludes that to reduce their values to a common system based upon all reliable parallaxes, the following corrections should be applied:

McCormick..........	+0″.0014
Allegheny...........	+0 .0039
Yerkes.............	+0 .0058
Sproul.............	−0 .0023
Mount Wilson.......	−0 .0093

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[2] The number actually listed in the volume is 261.

[3] *A. J.* 33. 17, 1920.

As the result of a similar investigation[4] made in 1918 but published only recently, Professor A. S. Flint concludes that "it seems possible that when general mean values come into consideration, there will remain some systematic error, although small, which must be taken into account."

Some of Boss's figures, above, seem unduly large, and I am more inclined to accept those of Mitchell and van Maanen and to conclude that all five series are free from systematic errors exceeding 0″.001 or 0″.002.

Passing to the second question, we note first that all of the published parallaxes are relative. To obtain absolute values we must add the (assumed) parallax of the comparison stars employed. This will always be small (both Mitchell and Schlesinger adopt +0″.005) and may be regarded as fairly reliable. Then there are occasional stars for which the different observed parallaxes are discordant in amounts far exceeding the probable errors. The true distances of these stars must remain in doubt until further investigations are made.

But disregarding these, there still remains a considerable number of stars for which the observed parallax gives no accurate measure of distance. These are the stars whose measured relative parallaxes come out negative or, if positive, with values no larger than the probable error. A single (unchecked) count of the six series of measures (including the Greenwich results) shows that of the 1013 separately listed parallaxes 152 have the value 0″.000 or else negative values; 111 have positive values less than or just equal to their probable error; and 141 have positive values greater than, but not more than double the size of their probable error. Stated as percentages, 26 per cent of these parallaxes are negative or have positive values which are not greater than their probable errors; 14 per cent more have positive values which are not larger than twice their probable errors.

The parallaxes of the first class merely indicate that the stars in question are not nearer to us, or are farther away from us, than the comparison stars employed. They give us no definite information as to the actual distances. Parallaxes in the second class must also be regarded as of little value so far as the distance of the particular stars is concerned, but they will be valuable in statistical studies.

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[4] "Comparisons of Photographic Stellar Parallaxes." *A. J.* **33**, 95, 1920.

Summing up, I think Sir Frank Dyson's statement[5] made in 1915 still holds good. He wrote, "The question may be asked, how near must a star be to us for its distance to be measurable? I think we may say 10 million times the Sun's distance. This corresponds to the small angle 0″.02 for the parallax." It corresponds also, as will be noted, to somewhat more than twice the average notable error of the parallaxes here under consideration.

Many of the individual parallaxes in these papers are of great interest, but we must be content with a single illustration. Barnard's star ($17^{h}54^{m};+4^{\circ}25'$) has the distinction of having the largest proper motion at present known, 10″.3 a year. Its parallax is also the largest of any in these lists and is, in fact, second in size only to that of *Alpha Centauri*[6]. That is, it is our second nearest neighbor among the stars. Its parallax has been measured with accordant results at the McCormick, Dearborn, Yerkes and Mount Wilson Observatories and we may accept the value 0″.53 as representing the true distance very precisely. The apparent magnitude is only 9.7, and in absolute brightness it is one of the very faintest stars known to us.

As an illustration of the importance that may attach to a precise knowledge of a star's parallax we may cite the star *Alpha Orionis*. Thanks to the marvelous efficiency of Michelson's interference method, and to the skill with which it has been applied at Mount Wilson, we know that the *angular* diameter is 0″.046 within a few thousandths of a second of arc. This in itself is an advance in knowledge of the greatest importance. But the *linear diameter*, the diameter in miles, of which so much has been said in the press reports, depends also upon the star's parallax. The best available data give this as about +0″.016. If this is correct, the linear diameter of the star is 2.94 astronomical units, or about 273,000,000 miles. But the parallax is still uncertain, probably by nearly half its full amount. If the true value is +0″.008, the linear diameter is about 546,000,000 miles; if it is +0″.024, the diameter is only 182,000,000 miles.

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[5] *The Observatory*, **38**, 298, 1915.

[6] Innes's faint star, *Proxima Centauri* is probably physically connected with *Alpha*.